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Assessing Ways of Experiencing Human-centered Design via Student Reflections

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Introduction

With a worldwide pandemic threatening the health of all, now is the time to ensure that we, the community of engineering educators, are actively providing the next generation of engineers with the skills and motivations necessary to address grand societal challenges in meaningful ways. One "grand challenge" for the engineering education community that we put forth is preparing engineering undergraduate students to meaningfully integrate stakeholders into their design-based thinking, a domain of work that is preceded by many others [1-3] and which is ostensibly an essential aspect of the design outcome of ABET program accreditation [4].

To this end, in this study, we seek to apply and validate an assessment strategy to categorize students' ways of experiencing human-centered design. We directly build on Zoltowski et al.'s [2] findings which suggest that engineering students experience human-centered design in seven categorically discrete ways. Guided by this prior study, we seek to address the research question, "To what extent can we use post-course open-ended written reflection data to identify engineering students' ways of experiencing human-centered design?" The use of reflection data to categorize students' ways of experiencing human-centered design is unique from other methods that have extended Zoltowski et al.'s work but may offer a more accessible assessment modality for design instructors. Thus, we hope to provide design instructors with an accessible and accurate approach to identify their students' current design-thinking tendencies by applying and validating this approach. Further, this study serves as a validation check of Zoltowski et al.'s [2] findings by substantiating the applicability of these categories. Finally, we hope this work serves as a guide for design instructors as they consider how to improve their students' consideration and integration of users into their human-centered design thinking processes in developmentally appropriate ways.

Background & Motivation

Human-centered design (HCD) has received increased attention in engineering education, perhaps catalyzed by the increased use of human-centered design by leading design firms such as IDEO. The human-centered design process prioritizes user considerations, where user needs inform each phase of design. Thus, human-centered design frameworks provide tools, techniques, and mindsets to guide designers as they iteratively incorporate user perspectives and feedback [5]. By actively involving users throughout the entire human-centered design process, either directly (e.g., participatory design approaches) or indirectly (through approaches reliant on empathy without user interaction), outcomes are designed with fewer errors, require less user-training and support, increase users' productivity, and elicit increased user satisfaction [5].

Many other design-thinking frameworks offer related strategies and mindsets for designers to leverage during design. For example, universal and inclusive design frameworks call forth considerations of user breadth and inclusivity, wherein the designer might ask, "To what extent will this design be accessible and useful to all stakeholders?" [6] Participatory design frameworks prioritize thinking of users as partners, thereby asking, "How well have I included and collaborated with users, particularly those potentially most affected by my design, throughout the design process?" [7, 8]. Finally, empathic design asks how designers might consider and integrate user needs throughout design processes, thereby asking, "Have I accurately understood and integrated stakeholder perspectives throughout my design process?"

Hence, numerous design-thinking frameworks prioritize stakeholder considerations in related but slightly distinct ways. Sanders and Stappers [9] offered a four-quadrant framework for categorizing design thinking methods which varied by two dimensions: (1) user as subject versus partner and (2) methodological emphasis based on design thinking versus research-based methods. They suggest that recent years have seen an evolutional shift from user-centered thinking frameworks, wherein designers engage with the user(s) separately from design tasks, such as concept generation and making, and then share findings from those tasks with the user. This approach is fundamentally distinct from oft-used co-design frameworks that situate users and designers as collaborators throughout all (or at least the majority) of the design processes.

While distinct, these various design thinking frameworks often overlap. Briefly, we use empathic design as an example, as Zoltowski et al. [2] found it to be the most comprehensive way of experiencing human-centered design among engineering students. Over the nearly 20 years following its concept by Leonard and Rayport [10], empathic design scholars have emphasized variable aspects of this approach, with variation including emphasis between design and research as well as how users are incorporated into the design thinking process [11]. Thus, in its short history, empathic design seems to have spanned the quadrants of Sanders and Stappers' four-quadrant framework. One helpful way to approach design thinking is to identify what foundational principles guide the design process rather than fixate on the title of design frameworks alone. For example, Mattelmaki et al. [11] suggested four key principles have guided empathic design processes over the years: (1) "Sensitivity toward humans"; (2) "Sensitivity toward design"; (3) "Sensitivity toward techniques," and (4) "Sensitivity toward collaboration." By focusing on design principles, such as these principles of empathic design, we move from a consideration of *empathy* alone to the essence of the framework.

This brief background section suggests a growing interest in strategies for engaging humans and users in the design thinking process. Variants of human-centered design offer related but potentially discrete strategies, mindsets, and approaches to design. In this study, we build on one framework that is based on engineering students' experiences, as described next.

Theoretical Framework

Discrete Ways of Experiencing Human-Centered Design

Zoltowski et al. [2] utilized a phenomenographic methodology to categorize different ways students experience, understand, and demonstrate human-centered design. Through this study, the researchers identified seven distinct ways of experiencing human-centered design:

1. Technology Centered
2. Service
3. User as Information Source Input to Linear Process

4. Keeping the Users' Needs in Mind
5. Understanding the Design in Context
6. Commitment to Involving Stakeholders to Understand Perspectives
7. Empathic Design

These ways of experiencing human-centered design varied along two interrelated axes (see Figure 1, taken from [2]), which represent variation in (1) student's understanding of users' and stakeholders' role in the design process and (2) the complexity of design skills that motivate a student's design process [2]. While these axes are separate, students demonstrate an increased understanding of these skills in tandem rather than independently [2].

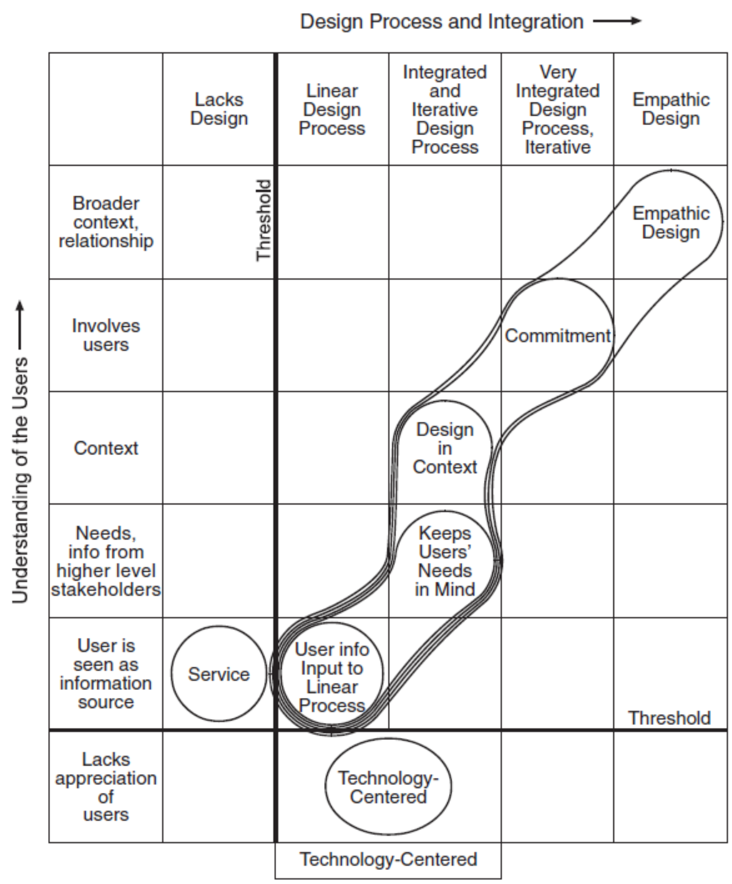

Figure 1. Variation in Ways that Students Experience Human-Centered Design (taken from [2])

Category 1 (Technology-Centered) and Category 2 (Service) show limited (or lack) appreciation of users and design, respectively, and thus are not deemed *ways of experiencing human-centered design*. Instead, these categories might be considered antecedents to other ways of experiencing human-centered design. Beginning with Category 3, "User as Information Source Input to Linear Process," the categories become hierarchically related, wherein each more 'comprehensive' category includes and builds on the design behaviors and attitudes of preceding categories [2]. Figure 1 shows the hierarchical relationship between these categories.

Category 7, "Empathic Design," describes the most holistic way of experiencing human-centered design [2]. According to Zoltowski et al., empathic design is characterized by a deep connection between the designer and the user that extends "beyond scope of the project" and into a deep contextual awareness of elements that affect the user (e.g., personal aspirations, sociopolitical factors) [2, p. 46]. As a result, individuals who demonstrate "Empathic Design" make design decisions based on information gained through meaningful connections with users, rather than on assumptions informed by a narrower understanding of the user and their context [2].

Using Reflection Data to Categorize Discrete Ways of Experiencing Design

Numerous scholars have utilized Zoltowski et al.'s [2] framework to categorize students' ways of experiencing human-centered design [12, 13]. Similar to Zoltowski et al. [2], Loweth et al. [14] categorized ways of experiencing human-centered design based on how students articulated the role and importance of user interactions in interviews. Other scholars have offered other research approaches to categorizes students' ways of experiencing human-centered design using this theoretical framework as a guide. For example, Jordan and Lande [15] categorized students' ways of experiencing human-centered design "based on how users were described in final project reports" (p. 10). Separately, Coso & Prichett [16] developed a rubric to evaluate how students integrate stakeholders into their design process by introducing two scaled criteria, "Stakeholder Integration" and "Design Understanding" (p. 6). These studies suggest growing interest and the general validity of Zoltowski et al.'s [2] framework, and we envision this study as further substantiating the robustness of this framework.

While the utility of Zoltowski et al.'s framework is apparent, we feel a more accessible and easily implementable assessment strategy may help other educators engage with students' ways of experiencing human-centered design. Interviewees are time-intensive and particularly become a challenge with large student groups. Student design reports and other group artifacts, which tend to be team-based, generally cannot identify the thinking of individual students. Thus, we seek to determine how effectively we can employ student reflection data to categorize students' ways of experiencing human-centered design based on the seven categories (see Figure 1).

Importantly, reflection-based activities are commonly used to support students' learning and can prompt students to holistically explore their educational experiences [17]. In engineering practice, reflection can also serve as a critical tool during the design process as engineers seek to refine their ideas through the iterative nature of design [18]. Thus, reflection activities have the pedagogical advantage of helping students contextualize the engineering design process [18]. For example, Turns et al. [19] describe a reflective essay assignment assigned to encourage students to "step away" from the design project requirements to reflect on their learning from the engineering design experience itself, rather than focusing on specific requirements. In short, by assigning written reflection activities, instructors can support students' growth towards more comprehensive ways of experiencing human-centered design. Thus, reflection activities offer both pedagogical advantages and the potential assessment opportunity to gain insight into what students learn from particular experiences.

Methods

Course Context

This work-in-progress study is set in the context of a large 100-level design and graphics course at a large Midwestern University. This course has two larger learning goals: (1) to introduce engineering design methodology, demonstrating the role of graphics in the engineering design process, and (2) to provide insight into the product design process, in particular as it relates to the architecture and functionality of the product. During Fall 2020, 34 student teams were introduced to the human-centered design process in a semester-long design project to address the challenge of eating lunch at a K-12 school during our current COVID crisis. Students were asked to design ways to prevent the spread of COVID-19 during lunch at a large school with a mechanical product that can be centrally manufactured and assembled, then distributed. Teams participated in the human-centered design process, including interviews with users and stakeholders, synthesizing insights, idea generation, and evidence-based decision-making before using Fusion 360 to model their final design prototype. The course instructor provided an overview lecture on the human-centered design process before teams participated in two TA-led 110-min labs covering interviewing participants and synthesizing insights from the interviews. Labs were co-developed by the course instructor and the cross-campus Design Center. In addition to submitting their final designs, students submitted an open-ended reflection written response. In these responses, students reflected on topics ranging from team dynamics, their personal growth as an engineer, and their thoughts about engineering and human-centered design.

Data Collection

In the last week of the semester, students submitted individual ePortfolios that described their team design project. The ePortfolio's template includes the following sections: (1) Home, (2) Designer & Team, (3) Project Description, (4) Ideation, (5) Product Analysis, (6) Design & Modeling, and (7) Reflection. The Reflection prompt stated:

> Talk about the challenges of this engineering design project. Include not only the details of this project and how it stretched you, but also what mistakes you made, how you navigated through its challenges, and what you perceived as the final outcome. Is there anything you would do differently next time you face a similar challenge? Your reflection can also be a time to celebrate your learning this semester.

A course assistant and instructor collected all reflections, copying the text of each reflection and compiling them into one course document, with all reflections numbered and anonymized. In total, 105 reflections were collected from the total 121 students who completed the course. Five students made their portfolios private, five students pursued the activity collaboratively, and five students did not complete the activity.

Data Analysis

The two researchers responsible for data analysis each coded all student reflections independently. The researchers assigned each student with one code corresponding to one of the ways of experiencing human-centered design, as defined by Zoltowski et al. [2] or "No Evidence" if no determination could be made. During the coding process, themes and 'keywords' related to each category of human-centered design understanding emerged and served as an inductively developed key for determining what category of human-centered design comprehension best characterized each student's reflection.

Interrater Reliability

We performed an interrater analysis to assess the degree that coders consistently assigned categories of experiencing human-centered design to reflection responses. We computed percent agreement as an initial check, although we recognize that percent agreement does not account for agreement by chance [20]. Thus, we also computed Cohen's [21] Kappa utilizing StataSE 16 and employed thresholds suggested by Landis and Koch [22] to identify the strength of interrater agreement.

Results

Interrater Reliability Analysis and Discussion

While both authors coded 69 reflection responses, we agreed to code seven additional passages after discussing coder disagreements, thus increasing our sample of coded responses to 76 of the 106 student reflections. Hence, the reflection data was insufficient to code 29 of the 105 responses (27.6%), thus indicating that the brevity of the reflection posts did not allow us to identify 'ways of experiencing' human-centered design among approximately one-quarter of respondents.

Descriptive Statistics

Analyses revealed that the majority of students (n = 47 or 68%) experienced human-centered design as primarily Technology-Centered (Cat. 1). Interestingly, the second and third most prominent ways of experiencing were User as Information Source (Cat. 3, n = 11 or 16%) and Keeping the Users' Needs in Mind (Cat. 4, n = 6 or 9%). Only two students experienced human-centered design as Service (Cat. 2), two as Understanding the Design Context (Cat. 5), and only one student exhibited a Commitment to Involving Stakeholders to Understand Perspectives (Cat. 6). No students demonstrated empathic design (Cat. 7). These findings indicate that upon the culmination of the course, students tended to experience human-centered in "less comprehensive" ways. In the discussion, we consider potential reasons why more student reflection posts did not exhibit more comprehensive ways of experiencing human-centered design.

Figure 2. Distribution of Ways of Experiencing Coded (categories align with [2])

Coding Considerations by Category

Our coding approach followed the following process: 1) Are users mentioned?, 2) If users are mentioned, how did the student discuss integrating that information in their design process? While coding the student interviews, we detailed our rationale for categorizing each student reflection. Additionally, we identified challenges that we faced when determining whether the category accurately represented the students' demonstration of their understanding of human-centered design. Below, we have summarized our common rationale and noted the common challenges we faced during the coding process for each Category.

Category 1: Technology-Centered Design ($n_{responses}$ =54)

Students who demonstrated a technology-centered understanding of human-centered design exhibited a fixation on the role of technology in the design process. Sometimes, this manifested as a description of the novelty, complexity, or 'coolness' of technology. These reflections omitted substantial discussion of the user, their needs, or information gleaned from user interviews. If the student mentioned users, they described the information gained from users as a means to an end pertaining to technology. Reflections commonly included detailed technical descriptions of the students' final deliverable that highlighted their final product's technical complexity, descriptions of how the individual parts of their design "fit together," and reflections about technical skill development (e.g., CAD, modeling).

Overall, the technology-centered student reflections did not discuss design as a process. As a result, students' reflections often focused on their struggles with learning a new modeling software, Fusion 360, or how they believed that their developing modeling skills would be an asset to their future engineering work. We believe that with some prompting, students who demonstrated a technology-centered understanding of human-centered design might have shared more insight into their perception of users' role in the design process.

Category 2: Service ($n_{responses}$=2)

Of the 105 student reflections, only two demonstrated a service-based understanding of human-centered design. In these reflections, the two students showed a fixation on helping others, generalized their users to ‘humans,’ and directly related the act of engineering to ‘helping.’ These reflections lacked insight about specific design strategies the students exercised to develop the solution, or the specific strategies were discussed only as an afterthought. Key phrases indicating a service-based understanding of human-centered design included “address[ing] the needs of people,” “[designing for] the welfare of all people,” and “[designing for] the profit of a company.” Furthermore, an overarching theme of ‘helping people’ evidenced these students' service-based understanding of human-centered design.

Categorizing student reflection data as Category 2 was more language-dependent than the coding for other categories. We found that our coding of these two reflections was largely dependent on the language that the students used to describe the goal of human-centered design coupled with an absence of more technical rhetoric. However, we recognize that more explicit prompting about student perceptions around design goals may have revealed a more comprehensive understanding of human-centered design among these respondents.

Category 3: User as Information Source Input to Linear Process ($n_{responses}$=11)

Students who demonstrated this category of understanding prioritized user information and the ideation phase of design. User information was often described as an “input” (i.e., a given) to the design process rather than something that should be revisited throughout the design process. Furthermore, Category 3 reflections described user information as something that should be ‘gathered’ from user interviews. Generally, students expressed a value or appreciation of their user’s perspectives. Furthermore, reflections in this category described final deliverables as needs-based solutions.

While students in Category 3 ostensibly valued user perspectives, it was often unclear if or how students applied user knowledge in design. In other words, it was difficult to discern whether students obtained a piece of information from the user interviews themselves or if the information was based on a preconceived assumption the student had about their user(s).

Category 4: Keeping the Users’ Needs in Mind ($n_{responses}$=6)

The common element found across Category 4 student reflections was an awareness of design’s iterative nature. Student reflections in this category discussed “pivoting” during the design process and compared design to a “trial-and-error” process resulting in iteration.

Similar to the primary coding challenge associated with Category 3, it was often unclear whether students iterated on their designs to promote alignment with the users’ needs, as described by Zoltowski et al. [2], or whether students were iterating for an ulterior purpose (e.g., to meet a course requirement). Furthermore, it was difficult to discern whether students aimed to address their stakeholders’ needs in design or whether students sought information from stakeholders to help progress the design process.

Category 5: Understanding the Design in Context ($n_{responses}=2$)

Student reflections in this category described how deliverables would operate in a particular context. Accordingly, Category 5 reflections indicated that students sought information about the context for more information about how the product or service should be designed. Students who demonstrated this understanding of human-centered design often wrote about their desire to gain "background" information about the user to understand how the users might interact with the design in a specific context associated with the problem.

We believe that students' limited opportunity to engage with their stakeholders resulting from the COVID-19 pandemic and course logistics may have inhibited students' abilities to engage in a Category 5 human-centered design experience. Had students sought more opportunities to engage with stakeholders, they may have articulated the value of the challenge's context in the design. This suggestion calls forth the critical role of immersion in users' contexts for experiencing human-centered design in more comprehensive ways, one of the key findings from Zoltowski et al. [2].

Category 6: Commitment to Involving Stakeholders to Understand Perspectives ($n_{responses}=1$)

We believe only one student reflection evidenced a Category 6 human-design experience. In their reflection, this student articulated a strong desire to share their final deliverable with stakeholders to elicit feedback about the degree to which the deliverable addresses the stakeholders' needs. This student sought to understand whether their team appropriately considered their users' perspectives in the design or if further iterations would be necessary if given the time to do so.

Zoltowski et al. [2] note that a shift from a Category 5 to Category 6 understanding is exemplified by a recognition that designers "need" to incorporate stakeholder perspectives, rather than designers "should" incorporate stakeholder perspectives (p. 39). We found that this nuanced distinction rendered it difficult to identify if students did not elaborate on their thoughts about stakeholder perspectives extensively, a challenge we attribute to the open-ended (i.e., non-prompted) reflections.

Category 7: Empathic Design ($n_{responses}=0$)

Our results suggest that no student reflections demonstrated Empathetic Design, as defined by Zoltowski et al. [2]. Thus, we have no findings concerning how this level of understanding manifests in student reflection data.

Student Reflection Response Word Count Descriptive Statistics

After coding the student responses, we averaged the number of words that students in each category provided in their reflection responses. We see a rough trend correlating higher word counts correlating with more comprehensive understandings of human-centered design, with the exception of Category 1 and Category 5.

Category Indicating Way of Experiencing Human-Centered Design	n	Word Count		
		Average	*SD*	*Median*
1	54	366	151	327
2	2	249	3	249
3	11	285	75	263
4	6	499	235	486
5	2	447	41	447
6	1	523	--	--

Table 1. Descriptive Statistics of Word Count by Categories of Experiencing Human-Centered Design (categories align with Zoltowski et al. [2])

Discussion

We structured this discussion around Wiggins and McTighe's [23] backwards design model. Thus, we begin with a consideration of developmentally appropriate learning goals followed by assessment considerations for attaining evidence of these learning goals and, in closing, instructional strategies that enable students to exhibit this evidence.

Identifying Developmentally Appropriate Learning Goals

We employed an outcome space [2] to categorize students' ways of experiencing human-centered design. Participants were students enrolled in an introductory engineering design course. As this was many students' first formal exposure to the human-centered design process, we were content with seeing many students experience human-centered design as Category 3 (*User as Information Source Input to Linear Process).* However, our findings revealed that many students experienced human-centered design as Category 1, thus demonstrating a technology-centered view of human-centered design. This finding indicates that we ought to employ more purposeful efforts to support student development to at least a Category 3 way of experiencing in future iterations of this course. This finding also makes it evident to us that we need to develop more purposeful human-centered design *learning objectives* to facilitate such development.

As we discovered in this study, instructors should be sensitive to what students know and understand, and, accordingly, instructors' *goals* and *objectives* should be based on this sensitivity. In other words, design instructors must account for students' current way of experiencing design and tailor their instruction to be developmentally appropriate. As Bransford et al. [24] argued, "The contemporary view of learning is that people construct new knowledge and understanding based on what they already know and believe" (p. 10). This key sentiment is captured by Vygotsky's [25] *zone of proximal development,* which suggests that instructors must be sensitive to students' current level of understanding and tailor instruction accordingly. Thus, design instructors must employ developmentally appropriate instructional strategies to support learning.

Extant outcome spaces in design can guide the creation of developmentally appropriate learning goals/objectives. While Zoltowski et al. [2] provide one framework for understanding variations in ways of experiencing design (i.e., human-centered design), other scholars have offered discrete (but related) outcome spaces. These frameworks often resemble developmental frameworks, indicating what constitutes less and more comprehensive ways of experiencing a phenomenon [26]. For example, Daly et al. [27] investigated ways of experiencing *design* among professional designers. Conversely, Dringenberg and Purzer [28] analyzed variation in ways of experiencing *ill-structured problems* in design among first-year engineers. Using these or other examples, instructors can assess learning objectives in a low-time-intensive manner, but that builds on the rich experiential work and findings of these prior authors.

Engineering design course instructors interested in other facets of design might consider employing other extant phenomenographic or developmental frameworks, assessing students' current ways of experiencing (via reflections or some other modality), and using this knowledge to create explicit learning goals aligned with students' level of preparedness. For example, if instructors hope that students will experience human-centered design in more comprehensive ways, they might employ Zoltowski et al.'s phenomenographic outcome space (as we did). In turn, they ought to identify what category of "ways of experiencing" human-centered design experience is most appropriate for their students to demonstrate at the end of the course. We also encourage others to employ outcome spaces that are not design-specific. For example, many students spoke to teamwork and leadership skills; thus, we concluded this study with the question, *is there a different or additional outcome space that might be more representative of the experiences that students described in their reflections?*

However, we encourage researchers to be cautious when implementing extant phenomenographic outcome spaces or developmental frameworks. As one example, we entered this study with an interest in empathy, but we did not categorize a single respondent as experiencing human-centered design as "empathic design" as described by Zoltowski et al. [2]. We caution against interpreting this finding as an overall lack of empathy among students. Others have found that engineering students tend to exhibit empathy throughout the design process [29-31]; thus, we postulate that empathy frameworks - such as Walther et al.'s [32] model of empathy in engineering or empathic design frameworks, such as the principles listed by Mattelmaki et al. [11] - can provide a useful heuristic for considering variations in how empathy manifests in design and how to support empathy in developmentally appropriate ways.

Creating Assessments to Elicit Student Ways of Experiencing Design

Once instructors have identified learning goals and objectives, they must decide what constitutes evidence representing student achievement of these objectives [23]. Zoltowski et al. [2] employed semi-structured interviews to classify students' ways of experiencing as a research tool, but interviews can be time-intensive. Thus, authors following Zoltowski have utilized a design task to categorize students' ways of experiencing [12, 13]. In contrast, a brief reflection activity enabled us to categorize most student reflections. This task was relatively low time-intensive, as evaluating over 100 student reflections only took each coder a few hours, supporting the viability of this approach for large samples of students. However, 25% of the student reflections did not contain sufficient evidence for us to categorize responses. Thus, there is a clear trade-off between these three discrete modalities of qualitative assessment. In short, interviews are much more time-intensive but allow one to ask follow-up questions and more thoroughly categorize responses and are perhaps the ideal modality. However, we think it is imperative to continue developing valid modalities for assessing students' ways of experiencing design while remaining cognizant of the feasibility of implementing such assessments, particularly with large class sizes.

Post-hoc, we explored how word length of reflections aligned with students' ways of experiencing human-centered design. We found that longer reflection responses tended to represent more comprehensive understandings of human-centered design. As a result, we questioned whether simply requiring that students reflect with more words might have revealed more comprehensive ways of experiencing human-centered design among reflections. Thus, we still ask, "How might we prompt more substantive reflections among students to ensure that we are accurately categorizing their ways of experiencing design?"

In reflecting on our reflection activity, we propose incremental changes to the assessment we employed in this study that may enhance our ability to code all student responses. Students provided reflections via ePortfolios at the close of the course, and the ePortfolio prompted students to consider 'their journey' as they reflected on the course. Thus, some students, particularly those who may not have seen design as a salient element of their first-year engineering journey, did not discuss design learning at length. We posit that explicitly priming students to consider 'their journey *as designers*' may ultimately help us categorize more responses. Additionally, we see value in explicitly asking students to reflect on the users at various design stages (e.g., developing criteria and constraints, selecting one design alternative, etc.) rather than only at the end of the course.

Identifying Instructional Strategies to Support Development

Learning goals and objectives should be based on what category of human-centered design experience students tend to demonstrate at the beginning of the course *and* should be aligned with students' ways of experiencing. In turn, instructional strategies designed in alignment with developmentally appropriate learning goals will be more likely to support engagement with human-centered design in developmentally appropriate ways. For example, it is unlikely that a single course will support students' development from Category 1 to Category 7 ways of experiencing human-centered design, and any instruction targeted toward such development is likely to fail due to misalignment with students' Zone of Proximal Development [25]. Indeed, no students in this study exhibited a Category 7 (i.e., *empathic design*) way of experiencing human-centered design. Cummings et al.'s [12] study focused on an intensive community-engagement experience and only found one student (out of 11) to reach Category 7. Thus, by assessing students' categories of understanding with respect to a specific phenomenon (such as human-centered design), instructors can identify their students' ways of experiencing and, in turn, generate developmentally appropriate instructional strategies to support student growth.

The introductory systems engineering course had learning objectives related to hand sketching, digital prototyping, and engineering design methodology. As a result, the instructor focused on technology-focused content while balancing larger learning goals. We postulate that this impacted students' understanding of human-centered design, as we found that many students' responses included comments about designing for the "project requirements" that assessed students' modeling competency. For some students, focusing on the project's technology components dictated by the CAD-based learning goals may have been a roadblock to a students' more comprehensive understanding of the human-centered design process. Based on this finding, we offer a few considerations that we may have better employed to help students experience human-centered design in more comprehensive ways.

First, we recognize that faculty must make instructional trade-offs, including "the selection of course content, the amount of time dedicated to specific activities, types of instructional methods, formats, and technologies, and assessment criteria and weightings" [33]. Aleong and Goldstein [33] found that engineering educators experience tensions as they must make decisions about how to teach and support students across a diverse set of learning outcomes (e.g., technical skills, engineering design, and professional development) [34]. To this end, we encourage design educators to consider Dewey's [35] principle of continuity, which emphasizes the importance of having students apply and build on their knowledge and abilities they bring with them from previous experiences; this may be prior curricular, life experiences, or even experiences throughout a single course.

Second, we offer *reflection* as a specific modality to promote continuity both within and across design courses. Not only can reflection support students' meaning-making of a course's learning objectives [28], but reflection is a key design skill [34, 36]. This sentiment is akin to Schon's [34] discussion on reflection-*in*-action versus reflection-*on*-action. For example, written student reflections throughout a course can prompt students to reflect on experiences they occur (i.e., in-action). Thus, instructors should aim to craft opportunities for students to engage in critical reflection during classroom experiences. While authentic learning opportunities (e.g., 'real-world' projects) often elicit reflective practice, they can be time-consuming to plan [37]. Thus, smaller, more frequent reflection exercises, such as the one examined in this study, present a way for instructors to elicit feedback and insights about students' learning, perhaps alleviating instructors of previously mentioned tensions associated with teaching engineering design. However, this is not without a cost. If instructors seek insights about students' growth, *continuous* reflections will likely be most effective at capturing students' experience, ultimately increasing the time instructors will spend engaging with student responses.

Third, we encourage instructors to consider how the course context, the design project, and other classroom activities might influence students' ways of experiencing design. As just one example, Cummings et al. [12] found service-learning experiences were a primary modality for supporting more comprehensive ways of experiencing human-centered design (most students ended the course at *Category 6*), and this was largely due to the *immersive* nature of these experiences. In the context of the course we studied herein, significant time was allocated to learning computer modeling software, and, as a result, immersion in stakeholders' lives was less prominent. As a result, it is perhaps unsurprising that so many students prioritized discussing technology-related learning gains. Thus, we hypothesize that we could promote more comprehensive ways of experiencing human-centered design simply by fostering (and perhaps requiring) meaningful and immersive interactions with users and stakeholders paired with more continuous reflection.

Finally, instructors should consider where their course falls within the students' undergraduate experience. Many engineering programs include a design sequence, where students apply an increasingly vast knowledge base from technical courses to increasingly more complex and human-centered design challenges. This presents an opportunity for faculty members to consider how students experience design across the curriculum. Thus, while design instructors often consider outcomes of their course in isolation of other courses, we encourage program developers to consider how best to assess students' development across the curricula. A simple open-ended reflection prompt at the conclusion of each semester, such as that utilized in this study, could provide a rich qualitative data source and would also help substantiate students' attainment of ABET-related design expectations. Furthermore, this presents an opportunity for departments to coordinate their programmatic efforts to provide students with a series of design experiences that nurture a students' more comprehensive understanding of human-centered design.

Future Work

This work prompted us to consider how we support and evaluate students' understanding of human-centered design in design courses and across engineering design curricula, ultimately setting the stage for future work. To improve the applicability of reflection data for assessing ways of experiencing human-centered design, we propose two directions for future work. First, we propose iterating and improving on the criteria used to assess students' understanding of human-centered design through reflection data. Using the categories proposed by Zoltowski et al. [2], we aimed to develop more robust guidance to help instructors assess their students' understanding of human-centered design via written reflections. Second, by explicitly asking students about the user throughout the design process, we can examine students' dynamic understanding of human-centered design longitudinally throughout their subsequent design experiences.

Conclusion

In this study, we examined the feasibility of employing categories of experiencing human-centered design identified by Zoltowski, Oakes, and Cardella [2] to assess open-ended student reflection data from an introductory graphics and design course. Our findings supported the use of open-ended reflections to categorize students' ways of experiencing human-centered design. Frankly, we were surprised by how well we could categorize student responses via brief reflection prompts alone. However, we were unable to code approximately a quarter of responses and thus also offered areas to improve this assessment modality in future use. We also found few students experiencing human-centered design in "more comprehensive" ways. Given that this was a first-year course, this finding was not alarming, but the preponderance of Category 1 ways of experiencing indicated that we ought to provide more developmentally appropriate instructional design methods to support student development. We suggest more continuous and slightly more structured reflection prompts as one potential means to this end. Finally, given the viability of applying these categories to these data, we encourage other researchers to consider how to employ existing developmental frameworks, such as those offered by phenomographic outcome spaces, to assess students' ways of experiencing design to promote more comprehensive ways of experiencing design among engineering students.

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